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# Water-Jet-Assisted Roadheaders

By Robert J. Timko, Bradley V. Johnson,
and Edward D. Thimons

UNITED STATES DEPARTMENT OF THE INTERIOR

(United States. Bureau of Mines)

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Donald Paul Hodel, Secretary

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Robert C. Horton, Director

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| Page 2, column 2, last line: Add "and" after "Bit wear was high," | 8 |
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| | 3 |
| the 200-psi conventional pressure. In cutting 235 ft of roadway, only | 3 |
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| | | | |
|---|---|---|---|
| ft | foot | kW•h | kilowatt hour |
| gal/min | gallon per minute | μm | micrometer |
| h | hour | pct | percent |
| hp | horsepower | psi | pound per square inch |
| in | in | st | short ton |

# WATER-JET-ASSISTED ROADHEADERS

By Robert J. Timko,[1] Bradley V. Johnson,[2] and Edward D. Thimons[3]

ABSTRACT

Water-jet-assisted cutting involves the use of a mechanical cutting bit in combination with a high-pressure water jet directed just in front of the bit tip. Such a jet can offer benefits in terms of improved cutting, reduced dust and fines, and improved bit wear. The Bureau of Mines, through a contract with the British National Coal Board, has researched the use of water-jet-assisted cutting on roadheaders. After several engineering design problems were overcome, this program led to the successful underground testing of these roadheaders. Today, more than 60 water-jet-assisted roadheaders are in operation around the world, and numerous others are on order. This paper details the evolution of these machines and the benefits to be gained by their use.

[1]Physical scientist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.
[2]Staff engineer, Division of Mining Technology, Bureau of Mines, Washington, DC.
[3]Supervisory physical scientist, Pittsburgh Research Center.

## INTRODUCTION

Mining through high-compressive-strength rock is expensive and time consuming. Two basic methods are employed: drilling and blasting and mechanical cutting. In many countries, the mechanical cutting is primarily accomplished by roadheaders.

Roadheaders were first developed in Hungary in the 1950's and are now used worldwide for mining a variety of soft- to medium-strength materials. The Bureau of Mines, through a contract with the British National Coal Board (NCB) (4),[4] has conducted research to improve the performance of these machines by equipping them with water-jet-assisted cutting capabilities. Based upon previous laboratory studies, it was believed that this addition would result in improved cutting, reduced bit consumption, decreased dust and fines, and possibly even reduced frictional sparking.

## PRELIMINARY WATER-JET-ASSISTED ROADHEADER STUDIES

### PROTOTYPE ROADHEADER DESIGN

The first roadheader to be modified for water-jet-assisted cutting was a Dosco Mk.IIA, which is a 24-st crawler-track machine capable of cutting both rectangular and arch-shaped roadways (fig. 1). Its cutting capacity is normally limited to rock with compressive strengths under 12,000 psi. This prototype was fitted with a water-jet-assisted system consisting of a high-pressure pumping system, a rotary seal, and water-jet nozzles (fig. 2).

The pumping system was a hydraulically powered intensifier (fig. 3). It consisted of a swashplate hydraulic pump driven by an electric motor that delivered pump-pressurized oil to the intensifier. Flexible hoses carried 2,000-psi oil from the pump to the intensifier. The pump was mounted on a sled behind the roadheader, and the intensifier was mounted on the cutting boom. High-pressure water, at a maximum flow of 12 gal/min at 10,000 psi, was carried from the intensifier to the cutting head via rigid steel pipe.

The cutting head, located at the end of the boom, was driven by a 65-hp electric motor. The boom was a turret, powered by hydraulic cylinders. The large, 5.5-in-diam cutting-head shaft required that the rotary seal handling the high-pressure water to the cutting head be large. The seal (fig. 4) was a BAL U-ring type seal, energized by an elliptical coil spring (fig. 5). The sealing faces were ridged to give three sealing points around the circumference of the opening. The seals were made of a graphite-filled Teflon fluorocarbon polymer.

The standard Dosco cutting head (fig. 6) has bits arranged in a three-start helix, with seven bits on each helix. Two sumping bits are located at the very front of the cutting head. The standard bits and bit blocks were replaced with circular-shank, forward-attack bits and blocks to allow the water jet to be produced parallel to the bit tip without adjacent bit-block interference. Fifteen synthetic sapphire, high-pressure nozzles were installed, five on each helix. Since there were 21 bits on the cutting head, not every bit had a nozzle. The nozzles were countersunk into the cutting head to protect them from damage. They could be selectively capped to increase the water flow to the remaining nozzles. The nozzle-to-bit-tip standoff distance was 5 in (fig. 7).

### PROTOTYPE CUTTING TRIALS

Initial cutting trials were held in a limestone mine in Middleton, Derbyshire (5). The compressive strength of the limestone was 17,000 psi, well above the normal cutting capability of the Dosco Mk.IIA (fig. 8). Cutting without the high-pressure water was very difficult. Bit wear was high,

[4]Underlined numbers in parentheses refer to references at the end of this report.

FIGURE 1.—Standard Dosco Mk.IIA roadheader.

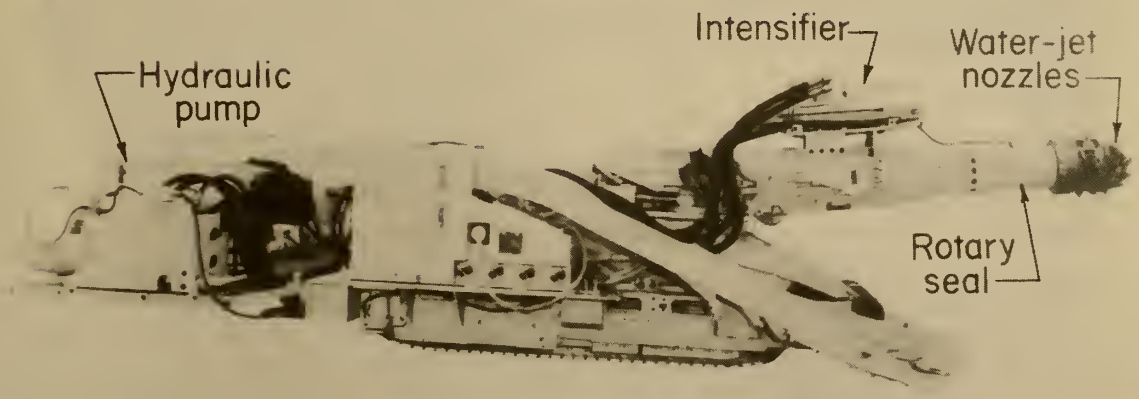


FIGURE 2.—Prototype NCB-modified Dosco Mk.IIA roadheader showing pump and intensifier.

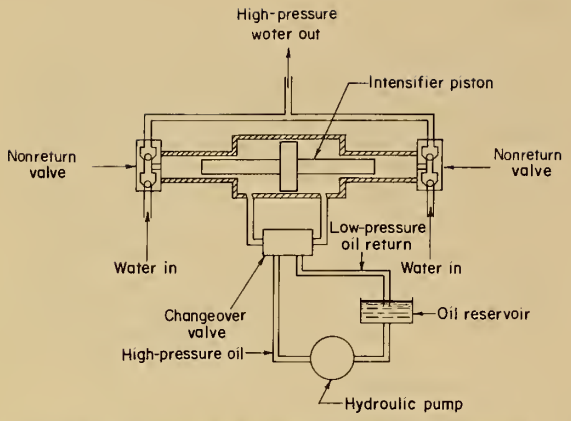


FIGURE 3.—Pumping sytem showing location of intensifier.

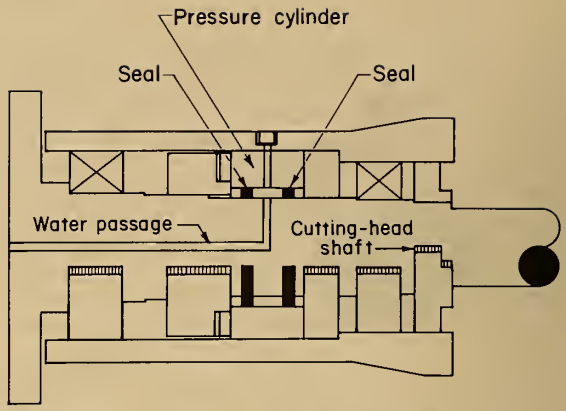


FIGURE 4.—Cutting-head shaft showing location of rotary seals.

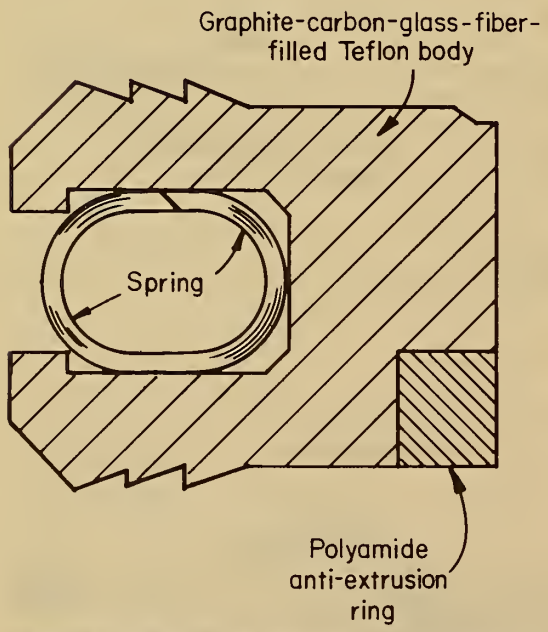


FIGURE 5.—Rotary seal schematic showing coil spring.

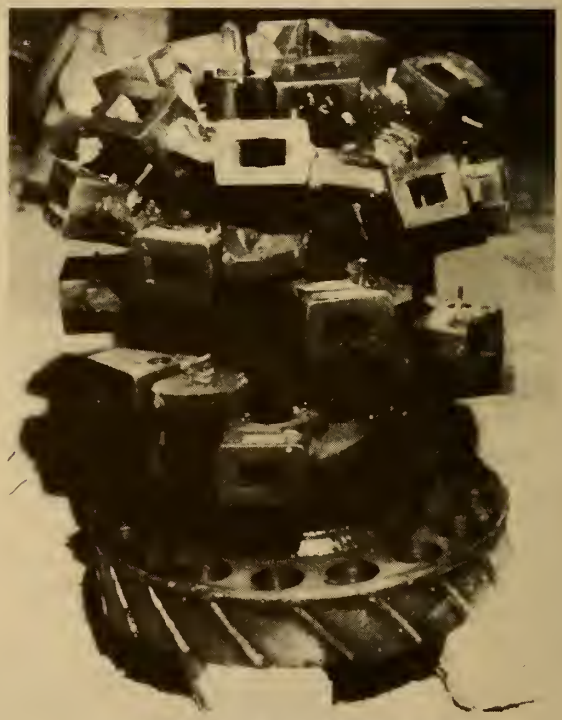

FIGURE 6.—Standard Dosco cutting head.

boom instability and bounce were problems. The addition of and 8,000- to 10,000 psi water-jet assist resulted in significant improvements. Bit wear, while still heavy, was greatly improved, and ma-chine vibration was visibly reduced. The overall cutting rate was approximately doubled, probably owing to proved bit wear.

For further testing, an artificial sandstone heading was constructed from eight 3-ft sandstone cubes laid two-high and cemented together with shotcrete (fig. 9). The compressive strength of

the sandstone was 6,500 psi. The sandstone was cut with and without water-jet assistance. Water-jet pressures between 6,000 and 10,000 psi were used. Flow rates were varied from 0.9 to 3.6 gal/min. No reductions in machine specific energy[5] resulted due to the water-jet assist, probably because of the softness of the rock. However, the high-pressure water did visibly eliminate frictional sparking and reduce dust.

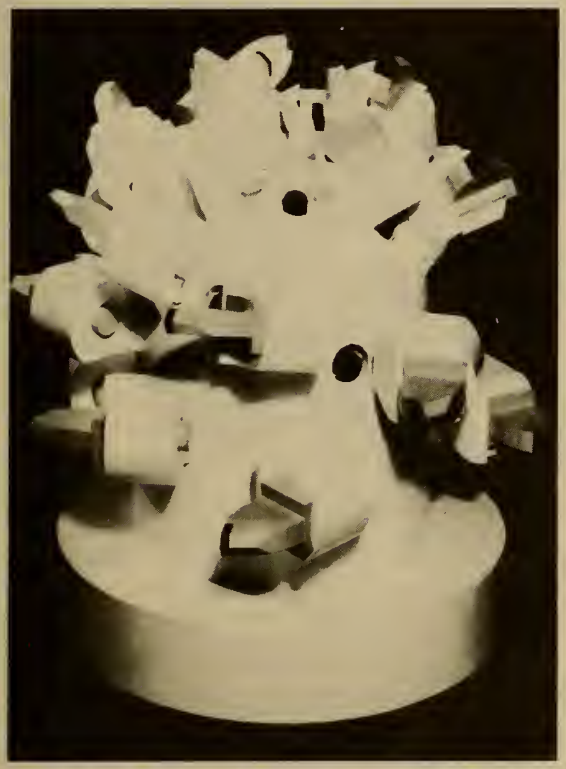

FIGURE 7.—Prototype NCB-modified water-jet-assisted Dosco cutting head.

Throughout this testing, the intensifier system worked without problems, as did the high-pressure jet nozzles, although occasional unplugging of jet nozzles was needed. No water leakage occurred at either the nozzle-cutting head interface and or the cutting head-drive shaft interface. The only major mechanical problem involved the life of the rotary seal, which varied during the testing from a minimum of 3 h to a maximum of 19 h. Because the seal is located in the cutting boom, each seal change caused considerable downtime. To deal with this problem, the NCB redesigned the seal to reduce its size. A cartridge assembly was developed that incorporated a small-diameter, readily accessible, easy-to-change BAL seal with a graphite-carbon-glass fiber-filled Teflon body. To install the seal in the boom, a layshaft gearbox was placed into

[5]Machine specific energy is the energy consumed by the machine without considering the energy required to supply the high-pressure water.

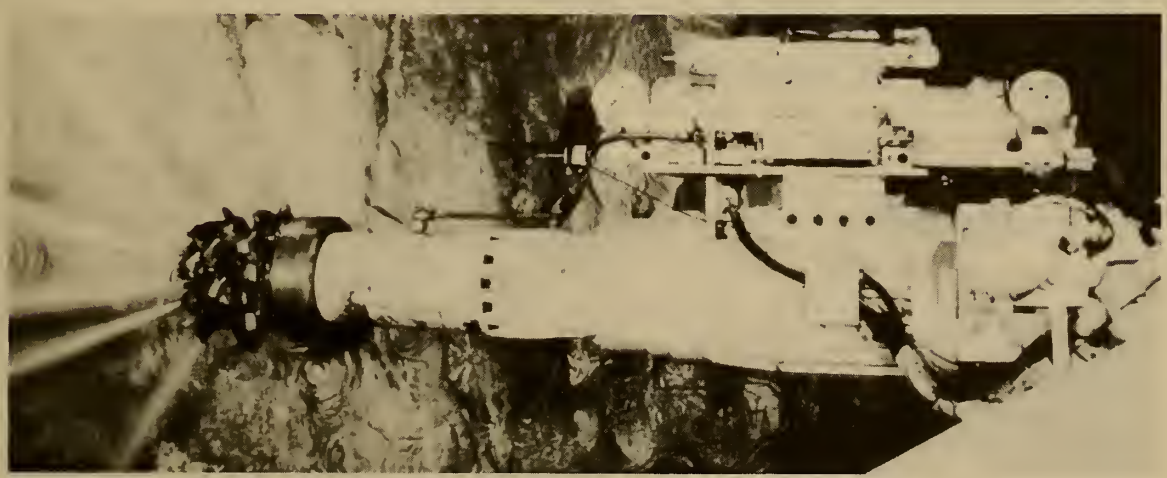

FIGURE 8.—Dosco Mk.IIA roadheader preparing to cut Middleton limestone using water-jet assist.

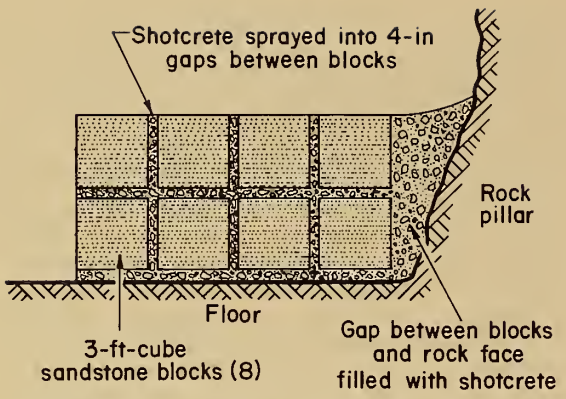


FIGURE 9.—Schematic diagram of artificial sandstone heading.

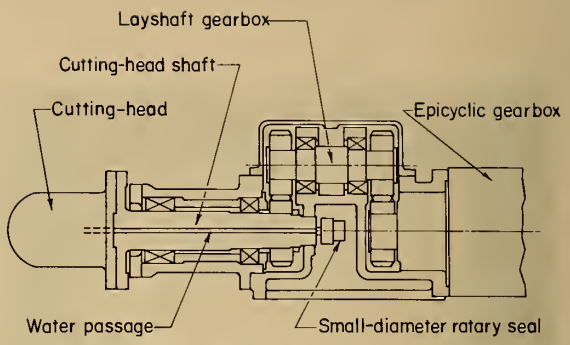


FIGURE 10.—Section through layshaft gearbox showing location of U-ring seal.

the boom in front of the cutting-head shaft (fig. 10). Laboratory tests with this new seal showed that a seal life of over 900 h could be expected.

## PREPRODUCTION WATER-JET-ASSISTED ROADHEADER RESEARCH

Following the prototype research described above, roadheaders were retrofitted with water-jet-assist capabilities by NCB and by two machine manufacturers, Dosco and Anderson Strathclyde. Each machine was evaluated separately in underground trials.

### NATIONAL COAL BOARD MODIFIED DOSCO ROADHEADER

#### Description

The NCB made several modifications to its prototype Dosco Mk.IIA roadheader. The oil-water intensifier, which provided a maximum flow rate of 12 gal/min at 10,000 psi, was powered by a swashplate hydraulic pump mounted on the rear of the machine. A valve assembly allowed the operator to select 10,000-psi water for harder strata or 2,000-psi water in softer rock for dust suppression only. The layshaft gearbox was installed in the boom. Water was plumbed from the intensifier, through the rotary seal, to the cutting head.

Tungsten carbide water-jet nozzles were installed on the cutting head; but unlike those on the prototype roadheader, these nozzles were raised above the cutting-head body to reduce the standoff distance from nozzle to bit tip to 3.5 in, creating a more concentrated water jet. To protect the nozzles from damage, they were surrounded by steel shrouds (fig.11). Supply water was filtered to 40 μm.

The water-jet system was interlocked with the roadheader's electric and hydraulic systems. In this way, the high-pressure water could only be turned on when the cutting head was running.

#### Cutting Trials

In the underground test, this machine cut a 240-ft-long entry in sandstone having a compressive strength of 13,000 psi. At 10,000-psi water pressure, bit life was doubled compared with that achieved using conventional cutting at lower water pressure. Significant dust reductions were seen up to about 3,000-psi water pressure with no additional improvement above that pressure. No frictional sparking was observed when the high-pressure water was on, but did occur when it was off. Unfortunately, no machine specific energy measurements were made (3).

Because the boom-mounted intensifier obstructed the operator's vision, it was remounted on the roadheader mainframe

with a shrouded flexible hose carrying water to the boom. The intensifier worked flawlessly. Contamination problems did occur in the hydraulic power pack that drove the intensifier, but regular flushing and filter changes rectified them. Debris in the water supply, even with the 40 μm filtration, caused repeated nozzle plugging, but the nozzles could be quickly cleaned with a twist drill bit.

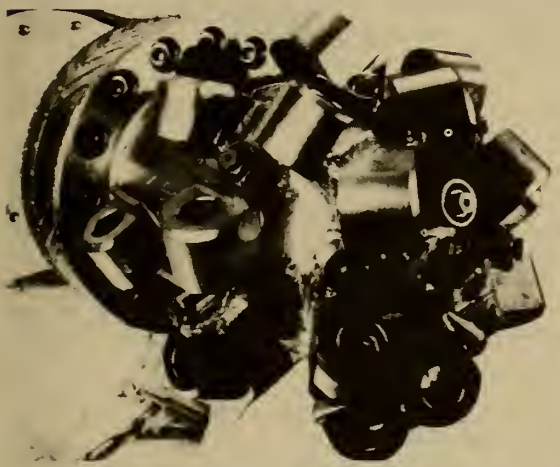

FIGURE 11.—NCB-modified Dosco cutting head showing steel shrouds used to protect nozzles from damage.

## MODIFIED ANDERSON STRATHCLYDE ROADHEADER

### Description

The Anderson Strathclyde RH22 is a medium-weight crawler-track machine that weighs 37 st and is usually limited to cutting rock with compressive strengths less than 14,000 psi (fig. 12). This machine was modified for water-jet assist by installing a triplex pump and header tank on the rear of the machine, behind the operator seat. Maximum water-pressure capability was 14,500 psi, but the pressure was limited by a relief valve to a maximum of 10,000 psi for safe operation. Water flow and output pressure could be varied from 4.75 gal/min at 580 psi to 19.8 gal/min at 10,000 psi by

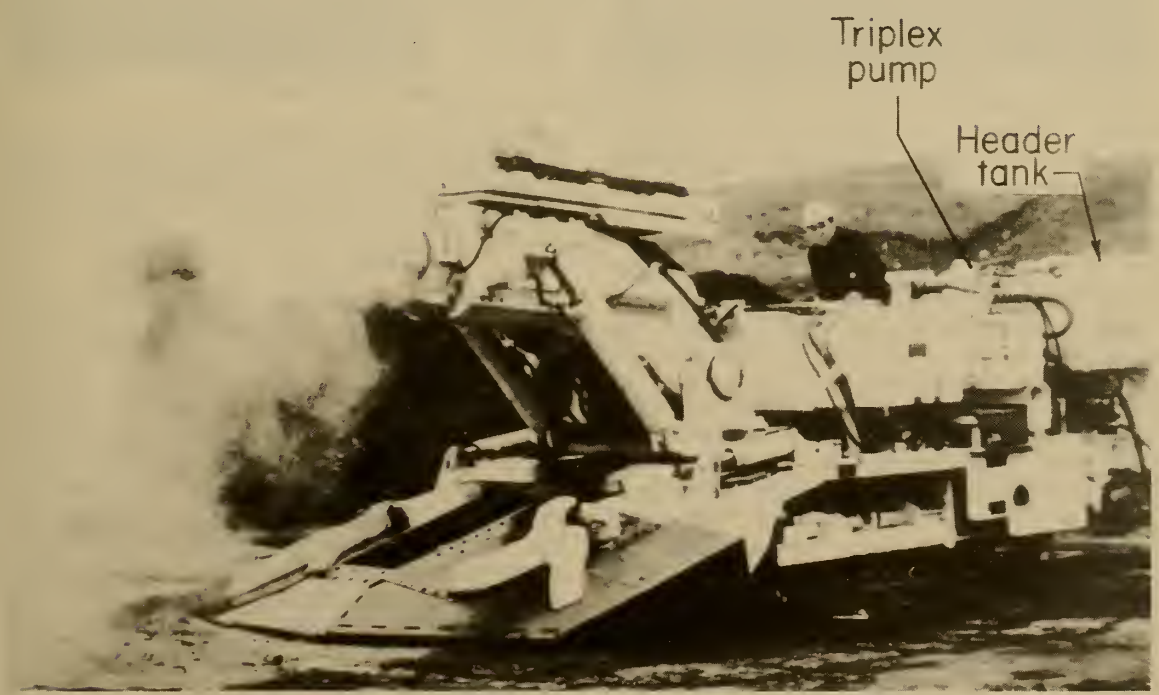


FIGURE 12.—Water-jet-assisted Anderson Strathclyde RH22 roadheader.

maneuvering a single joystick located at the operator position.

The RH22 boom contained an axial water passage with a small-diameter rotary seal at the motor end. Because the boom telescopes, a sliding seal was built into the water passage on the cutting-head end. High-pressure water was fed to the cutting head through a flexible hose, which was shrouded for safety by a second, larger diameter flexible hose. The cutting head was a standard RH22 cutting head with tungsten carbide high-pressure nozzles installed in front of each of the 24 bits.

### Cutting Trials

This RH22 water-jet-assisted roadheader was tested in the Sutton Manor Colliery, where it was used to drive a 1,150-ft entry in rock of compressive strength up to 24,000 psi. Operating at 10,000 psi, water-jet assist resulted in a 50-pct increase in advance rate over normal operation at 100 psi (1). There was a decrease in machine specific energy of about 30 pct, although the total specific energy[6] actually increased when the pumping energy was considered. A respirable dust reduction of 70 pct occurred as the water pressure was raised from 100 psi to 3,000 psi. Additional increases in water pressure had no effect on dust levels. Machine vibration was visually reduced, and no frictional sparking was evident when the high-pressure water was used. Significant reductions in bit wear occured. At 10,000 psi, bit wear was as low as 0.20 bit/ft of advance as compared to normal bit wear of 0.83 bit/ft of advance. The greatly improved bit wear may have been responsible for much of the increase in advance rate.

A bit longevity experiment was performed by plugging one of the front jet nozzles. In cutting an advance of approximately 3 ft, the bit that received no water owing to the closed nozzle had to be replaced three times, while only one other bit on the entire cutting head had to be replaced.

[6]Total specific energy is energy required to supply high-pressure water plus the machine specific energy.

Overall, this machine performed well during the cutting trials. A few problems did occur. The sliding seal on the telescoping boom failed and had to be redesigned in order to improve its durability. Additionally, nozzles frequently became plugged owing to impurities in the water supply, but these orifices were easily cleaned with twist drills having the same diameter.

## RETROFITTED DOSCO ROADHEADER

### Description

Dosco retrofitted an Mk.IIA roadheader with a water-jet-assist system similar to that used on the NCB prototype, except that the water pump was installed on the roadheader frame (fig. 13). Dosco used the NCB-developed layshaft gearbox with its small-diameter seal. The high-pressure water was delivered to the cutting head via rigid steel pipe with horizontal and vertical articulating joints to accommodate movement of the boom. Synthetic sapphire, water-jet nozzles were supplied in front of the bits on the standard Mk.IIA hardrock cutting head (2).

### Cutting Trials

This machine was tested in the Bentinck Colliery where the strata ranged from soft mudstones to hard laminated sandstones, having compressive strengths approaching 20,000 psi. It was used to enlarge an existing roadway. Floor water problems resulted in the high-pressure water being used only intermittently, and conclusive data on its performance were not obtained.

Several mechanical problems with the rotary seal did develop. Owing to metallic contamination of the water supply, the rotary seal eroded and failed after very short periods of use. This problem was overcome by using impoved hydraulic components. Additionally, the high cyclic loading generated by the eight-cylinder pump and the rigid steel pipe caused another failure of the rotary seal. This problem was solved by replacing the eight cylinder pump with

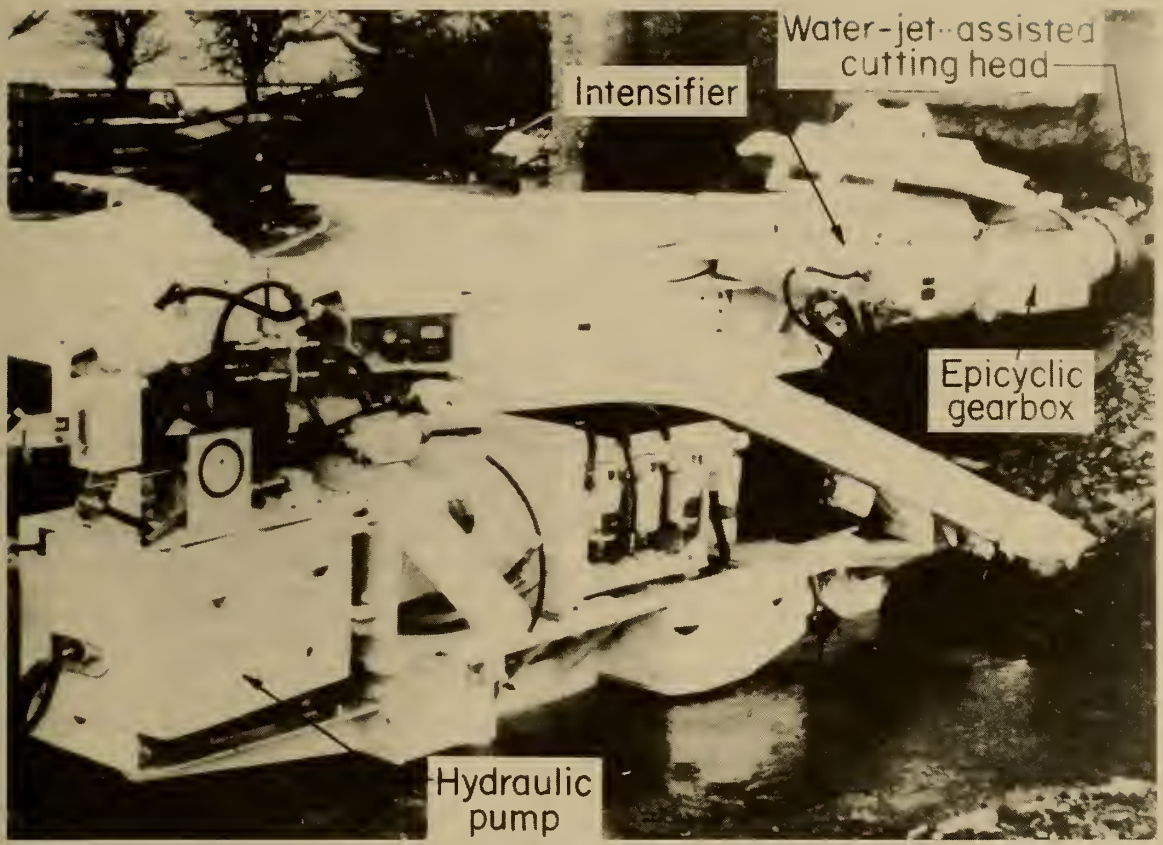


**FIGURE 13.—Retrofitted water-jet-assisted Dosco Mk.IIA roadheader**

a four-cylinder version and substituting flexible hose for the steel pipe (6). With these modifications, the rotary seal was able to operate for approximately 900 h before breakdown.

## CURRENT WATER-JET-ASSISTED ROADHEADER STATUS

Both Anderson Strathclyde and Dosco now commercially market water-jet-assisted roadheaders. More than 60 of these machines are operating around the world, and many more are on order. They are available in a variety of machine weights and have water-jet-assist capabilities ranging from 2,000 to 10,000 psi. In addition, Dosco offers a water-jet-assist retrofit system for roadheaders that already have a water lance through the boom. The average price of the retrofit system is about $75,000.

Currently, three Dosco Mk.IIB and two Anderson Strathclyde RH22 water-jet-assisted roadheaders are in operation at the Cape Breton Development Corp.'s Phelan Sydney, NS (Canada). These roadheaders are cutting five parallel development drifts on a 16° slope. Some mechanical problems, such as leaking seals and plugged water-jet sprays, have occurred but overall performance has been good and the mine has ordered two more water-jet-assisted machines. These will be low-profile Dosco L-1300 roadheaders with 3,000-psi water-jet capability. Dust measurements made by the Canada Centre for Mineral and Energy Technology (CANMET) on the roadheaders at this mine showed dust reductions as much as 80 pct greater than conventional spray systems

with 3,000-psi water pressure; no further reductions occurred as the pressure was increased above this level. At 10,000 psi, there was no increase in cutting advance rate when cutting rock or coal.

Both Dosco and Anderson Strathclyde now feel that for many mining operations, especially in softer materials, water pressures well below 10,000 psi will be sufficient to gain the benefits of water-jet-assisted cutting in terms of dust reductions, bit wear improvements, frictional-sparking reductions, and decreased fines. Lower pressure machines will also entail fewer engineering design problems, cost less, and be safer and more economical to operate.

Dosco recntly supplied a medium-pressure water-jet-assisted Mk.IIB roadheader to the Beringen Mine in Belgium. This machine was specially designed to deliver a maximum water-jet-assist pressure of 3,000 psi. In place of the large electric motor and pump required for 10,000-psi operation, this machine employs a compact three-cylinder positive-displacement hydraulic pump capable of supplying 10.5 gal/min at 3,000 psi. The water is delivered to 20 of the 24 cutting bits. For approximately 6 months, this roadheader has been cutting coal having banded rock intrusions with compressive strengths of 14,000 psi. At 3,000-psi water pressure, respirable dust was reduced by 75 pct from its level at the 200-psi conventinal pressure. In cutting 235 ft of roadway, only 5 bits had to be replaced at 3,000-psi water did not reduce the machine specific energy, indicating that no cutting-force reductions occurred. In fact, there was a slight increase in total specific energy due to the energy required to supply the 3,000-psi water.

An Anderson Strathclyde RH22 roadheader with 5,000-psi water-jet assist has been successfully operating at the Kellingly Colliery in North Yorkshire. Cutting dry, an average of 60 bits per day had to be replaced, but at 5,000 psi, the average was only 24. Although no dust measurements have been made, there was a significant visual reduction in dust when the 3,000-psi water was used.

Currently, research is being done by NCB and by Bergbau Forschung of the Federal Republic of Germany to determine the effect of higher water-jet-assisted cutting pressures (20,000 psi and above) on roadheaders. While major reductions in dust and bit wear can be achieved at lower pressures, it is believed that much higher pressures are needed to have a significant impact on cutting forces. The West Germans have demonstrated that, as the water pressure on a roadheader was raised from 0 to 21,000 psi, the machine energy consumption fell from 130 to 85 kW·h. However, the total energy consumed increased from 130 to 310 kW·h. Thus, the cost of operating at these higher pressures is significant. The West Germans are willing to accept this if it makes it possible for them to effectively cut the high-compressive-strength rock they encounter in their mining operations.

## SUMMARY

Testing of water-jet-assisted roadheaders has shown that significant respirable dust reductions occur at pressures approaching 3,000 psi. Raising the water pressure above that level has no effect on dust reduction. Improved bit wear and reduced frictional sparking also result, but the optimum water pressures to obtain these benefits are not as clearly defined.

A reduction in machine specific energy (improved cutting) was also seen in the cutting of harder materials, but was not evident in the cutting of lower-compressive-strength materials such as coal and soft rocks. However, the total specific energy always increased owing to the energy required to supply the high-pressure water to the nozzles.

More than 60 water-jet-assisted roadheaders are in operation worldwide, and several others are on order. These have water-jet pressure capabilities ranging from 2,000 to 10,000 psi. Currently, European researchers are concentrating their efforts on studying the effects of

European researchers are concentrating their efforts on studying the effects of water-jet assist on high-compressive-strength materials by using water pressures of 20,000 psi and above.

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